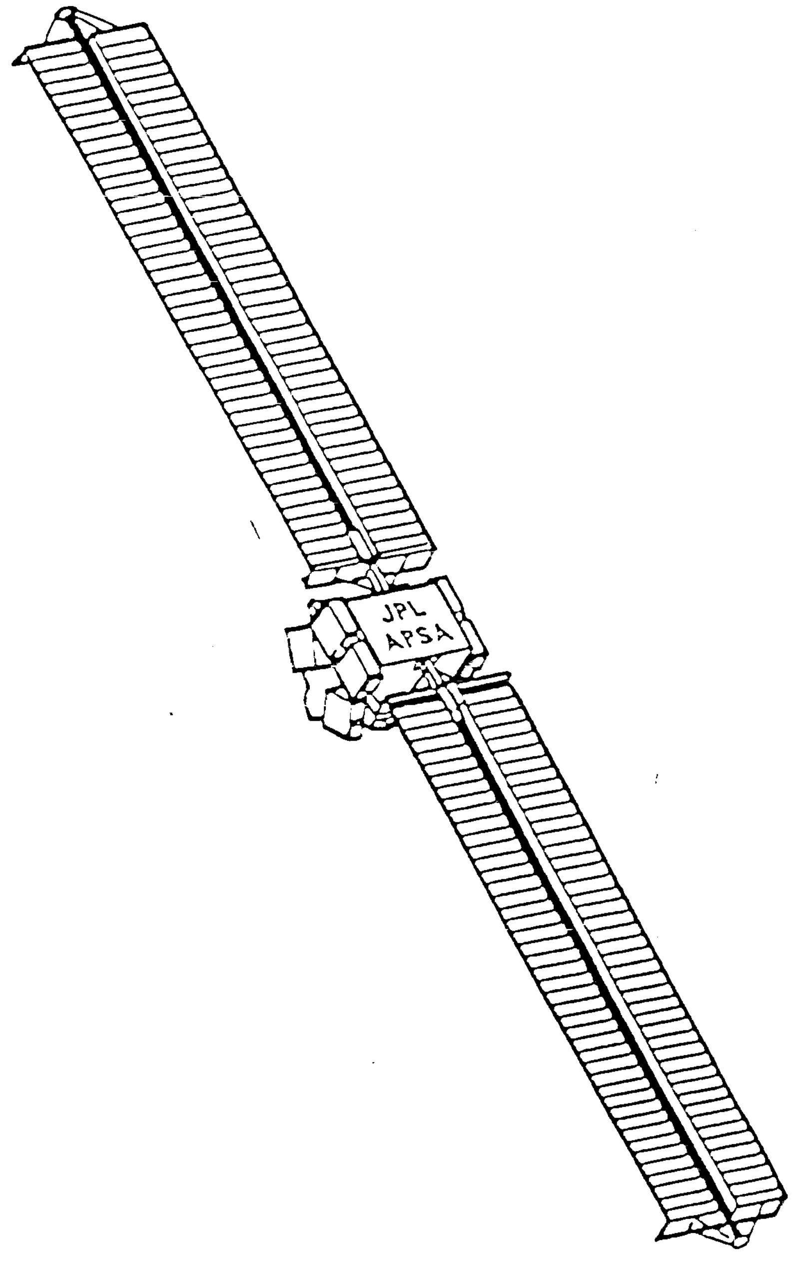
JPL NASA TRW




# Reverse Bias Characteristics of Thin BSF/BSR Silicon Solar Cells For Advanced Photovoltaic Solar Array (APSA)

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# REVERSE BIAS TESTING OF THIN BSF/BSR CELLS
## BACKGROUND

- A RECENT STUDY CONCLUDED THAT APSA SOLAR ARRAY CIRCUIT PROTECTION IS REQUIRED TO COUNTERACT THE EFFECTS OF HOTSPOTS GENERATED BY
  - SHADOWED CELLS AND
  - CRACKED CELLS.
- REVERSE CHARACTERISTICS OF THIN BSF/BSR SILICON CELLS ARE NOT WELL ENOUGH UNDERSTOOD TO DETERMINE THE NEED FOR BYPASS DIODES, PERFORM TRADE-OFF STUDIES, AND TAILOR THE APSA SOLAR ARRAY DESIGN.
- CIRCUIT PROTECTION WOULD HAVE A MAJOR IMPACT ON BLANKET DESIGN AND MANUFACTURING COMPLEXITY.
- NEED FOR EXPERIMENTAL DATA BASE TO DEFINE THE CELL REVERSE BIAS CHARACTERISTICS AND DETERMINE THEIR EFFECTS ON PV PROPERTIES OF THE DEVICES.

# APSA SOLAR CELL REVERSE BIAS TEST PROGRAM
# TEST MATRIX

- INVESTIGATED THE FOLLOWING ENVIRONMENTAL EFFECTS AND IMPACTS OF OPERATIONAL STRESSES INDUCED ON APSA CELLS UNDER REVERSE BIAS CONDITIONS:
  - A. CURRENT DENSITY EFFECTS TO DETERMINE THE THRESHOLD OF FAILURE DURING REVERSE BIASING.
  - B. PULSED REVERSE BIAS TESTING.
  - C. LONG DURATION REVERSE BIAS TESTING.
  - D. CELL REVERSE CHARACTERISTICS AS A FUNCTION OF TEMPERATURE.
  - E. EFFECTS OF CHARGED PARTICLE IRRADIATION ON CELL REVERSE BIASING.
- PERFORMED FAILURE MODES ANALYSIS AFTER CONCLUSION OF TESTS.

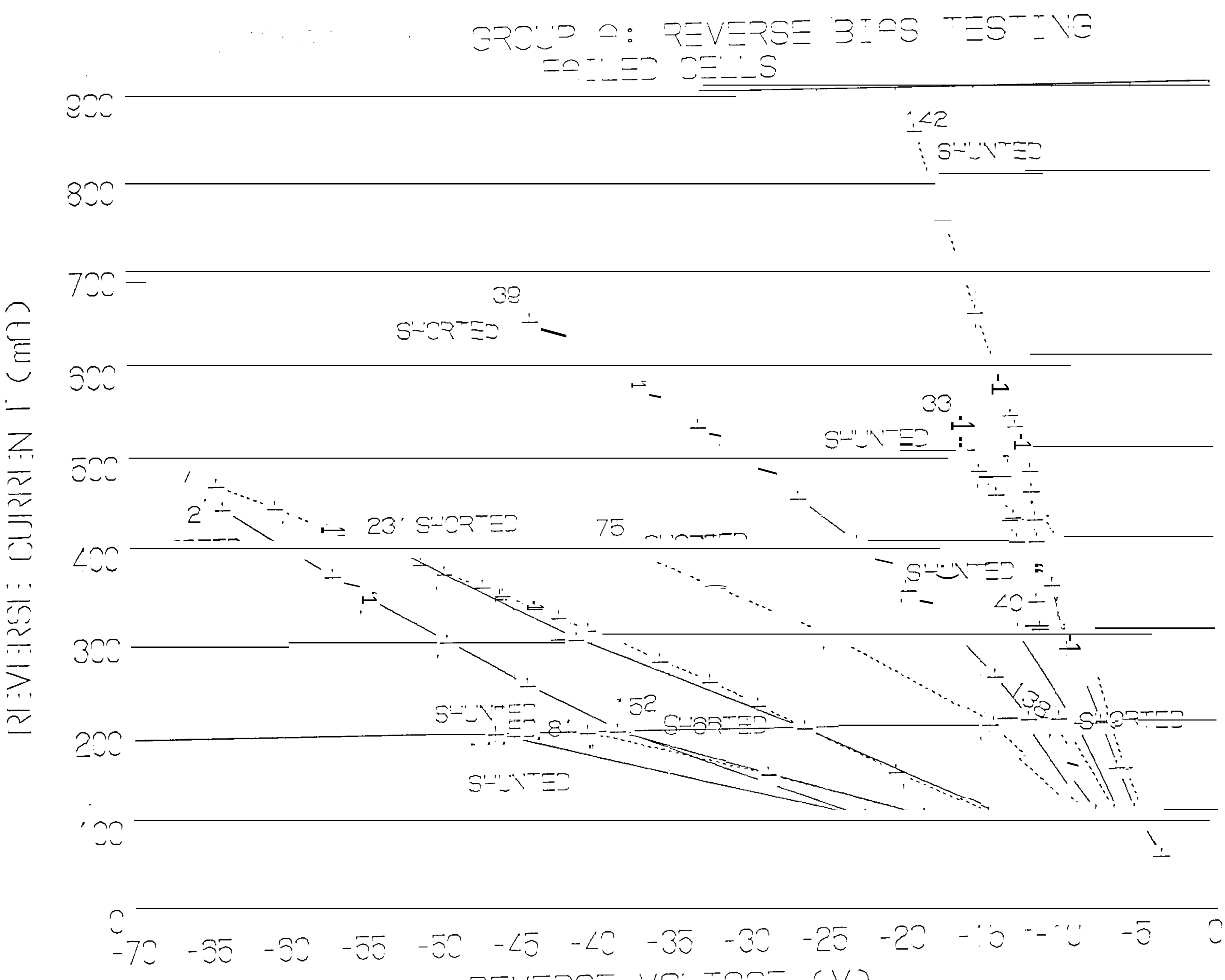
# CURRENT DENSITY EFFECTS ON CELL REVERSE BIASING
# TEST ARTICLES/TEST DESCRIPTION

- TEST ARTICLES:
  - -32 PRODUCTION GRADE, THIN BORON-DIFFUSED BSF/BSR SILICON SOLAR CELLS, FABRICATED BY VENDOR A, 2.5 X 5.1 X 0.007 CM, COVERED WITH 0.005 CM THICK UVR COATED CERIUM-DOPED BOROSILICATE GLASS.

- TEST SEQUENCE:
  - INITIAL P-V CHARACTERISTICS (AM0, @ 28 C).
  - REVERSE BIAS TESTS (RBT) AT AMBIENT CONDITIONS.
    - * REVERSE CURRENT WAS INCREASED IN INCREMENTAL STEPS OF 100 mA TO CELL BREAKDOWN VOLTAGE.
    - * RBT WERE MADE AFTER READINGS HAD STABILIZED.
    - * PV MEASUREMENTS TAKEN AFTER EACH RBT.
  - SOME CELLS WERE TAKEN TO FAILURE TO ESTABLISH THE THRESHOLD OF FAILURE.

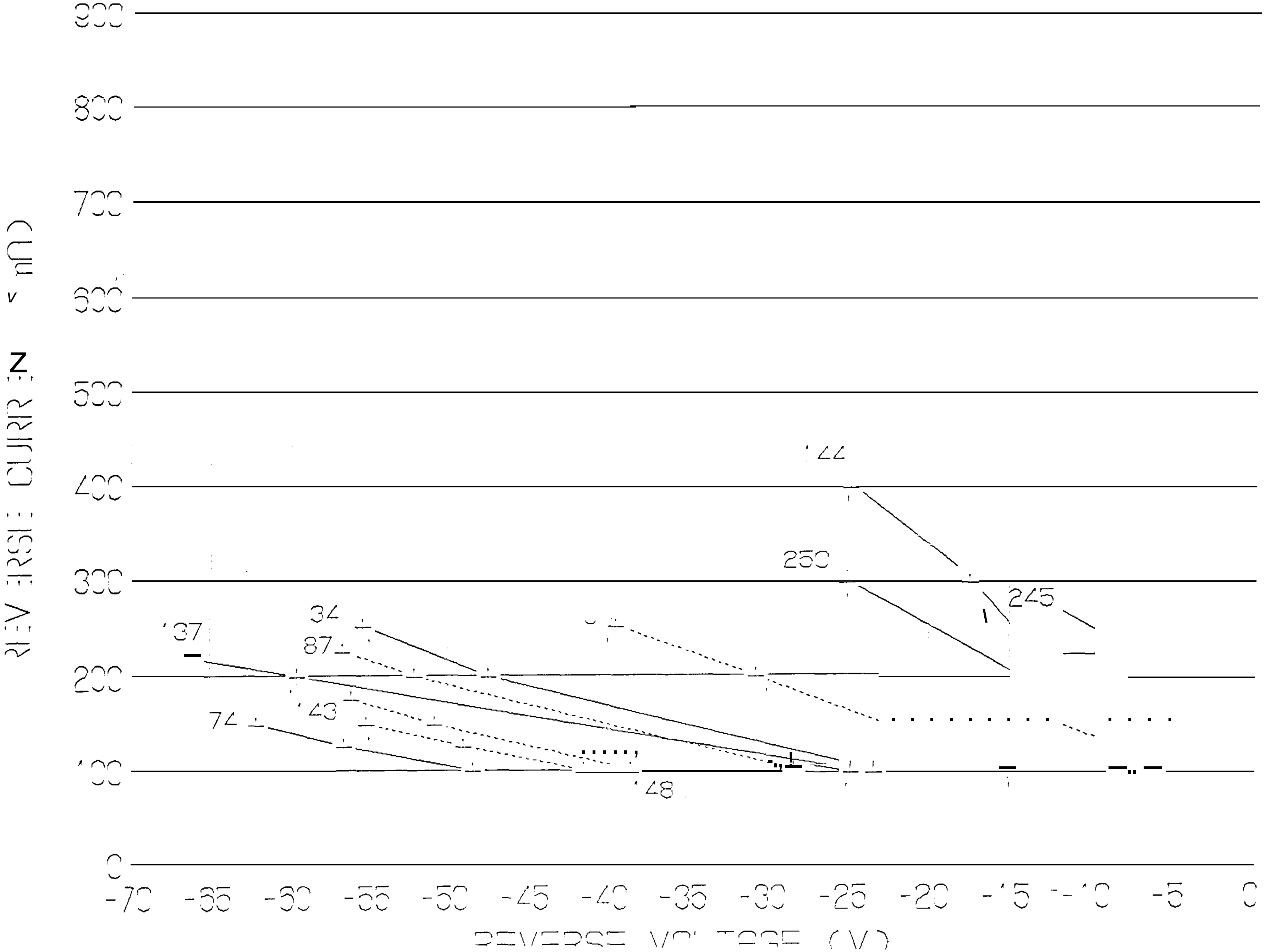
# CURRENT DENSITY EFFECTS ON REVERSE CHARACTERISTICS. RESULTS FOR CELLS FABRICATED BY VENDOR A

- RESULTS INDICATE WIDELY DISTRIBUTED REVERSE CHARACTERISTICS OF CELLS FABRICATED BY VENDOR A:
  - 15% EXHIBITED LOW VOLTAGE ($V_r$ < 20 V), HIGH CURRENT (> 0.5 Isc). CELL Isc APPROX. 520 mA.
  - 13% FELL WITHIN INTERMEDIATE VOLTAGE ($V_r$ BETWEEN 20 V AND 40 V) AND CURRENT RANGE (APPROX. 0.5 Isc).
  - 72% HAD HIGH VOLTAGE ($V_r$ > 40 V), AND A LOW REVERSE CURRENT (< 0.5 Isc).
- 12 OF THE 32 CELLS (38%) WERE TAKEN TO FAILURE:
  - 6 CELLS SHUNTED.
  - 6 CELLS SHORTED.
- NONE OF THE SAMPLES FAILED 'OPEN CIRCUIT".
- POWER DISSIPATION AT FAILURE RANGED FROM ().2 TO 2.3 $W/CM^2$ AND AVERAGE DISSIPATION OF UN FAILED CELLS WAS 0.85 $W/CM^2$.
- PV CHARACTER ISTICS OF UN FAILED CELLS WERE NOT AFFECTED BY RBT.



GROUP A: REVERSE BIAS TESTING
FAILED CELLS
REVERSE CURRENT (mA)
900
800
700
600
500
400
300
200
100
0
-70
-65
-60
-55
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
0
REVERSE VOLTAGE (V)
142
SHUNTED
39
SHORTED
33
SHUNTED
2
23 SHORTED
75
40
138
SHORTED
52
SHORTED
8
SHUNTED
SHUNTED

FIGURE 2-4. GROUP A: REVERSE BIAS TESTING
UNFAILED CELLS



# CURRENT DENSITY EFFECTS ON REVERSE CHARACTERISTICS RESULTS FOR CELLS FABRICATED BY VENDOR B

- STEADY STATE REVERSE BIAS TESTS WERE ALSO PERFORMED ON THIN BSF/BSR CELLS FABRICATED BY VENDOR B WITH ION-IMPLANTATION PROCESS.
- REVERSE CHARACTERISTICS OF VENDOR B CELLS FALL INTO PREDICTABLE CURRENT VOLTAGE RANGE.
  - 100% EXHIBITED HIGH VOLTAGE (Vr 46 V) AND LOW CURRENT (APPROX 0.2 Isc) BASED ON A QUANTITY OF 12 DEVICES.
- FIVE OF THE TWELVE CELLS WERE TAKEN TO FAILURE:
  - 1 CELL SHUNTED
  - 4 CELLS SHORTED.
- NONE OF THE SAMPLES FAILED "OPEN CIRCUIT".
- THE UNFAILED CELLS SURVIVED TO THE HIGHEST ACHIEVABLE REVERSE VOLTAGE (POWER SUPPLY WAS VOLTAGE LIMITED TO 66 V).
- PV CHARACTERISTICS OF UNFAILED CELLS WERE NOT AFFECTED BY RBT.

FIGURE 2-8. IR&D THIN CELLS: REVERSE BIAS TESTING
FAILED CELLS

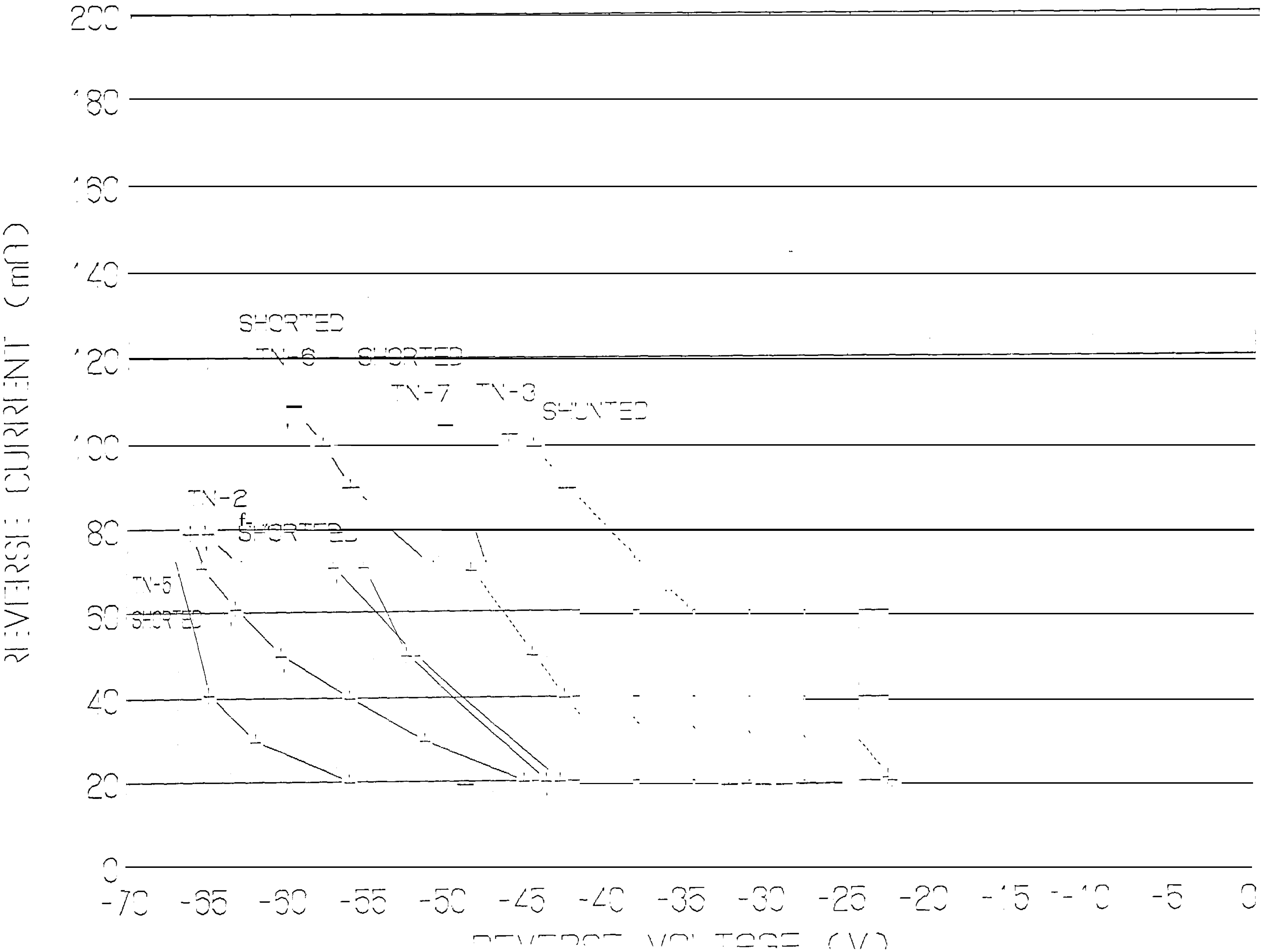
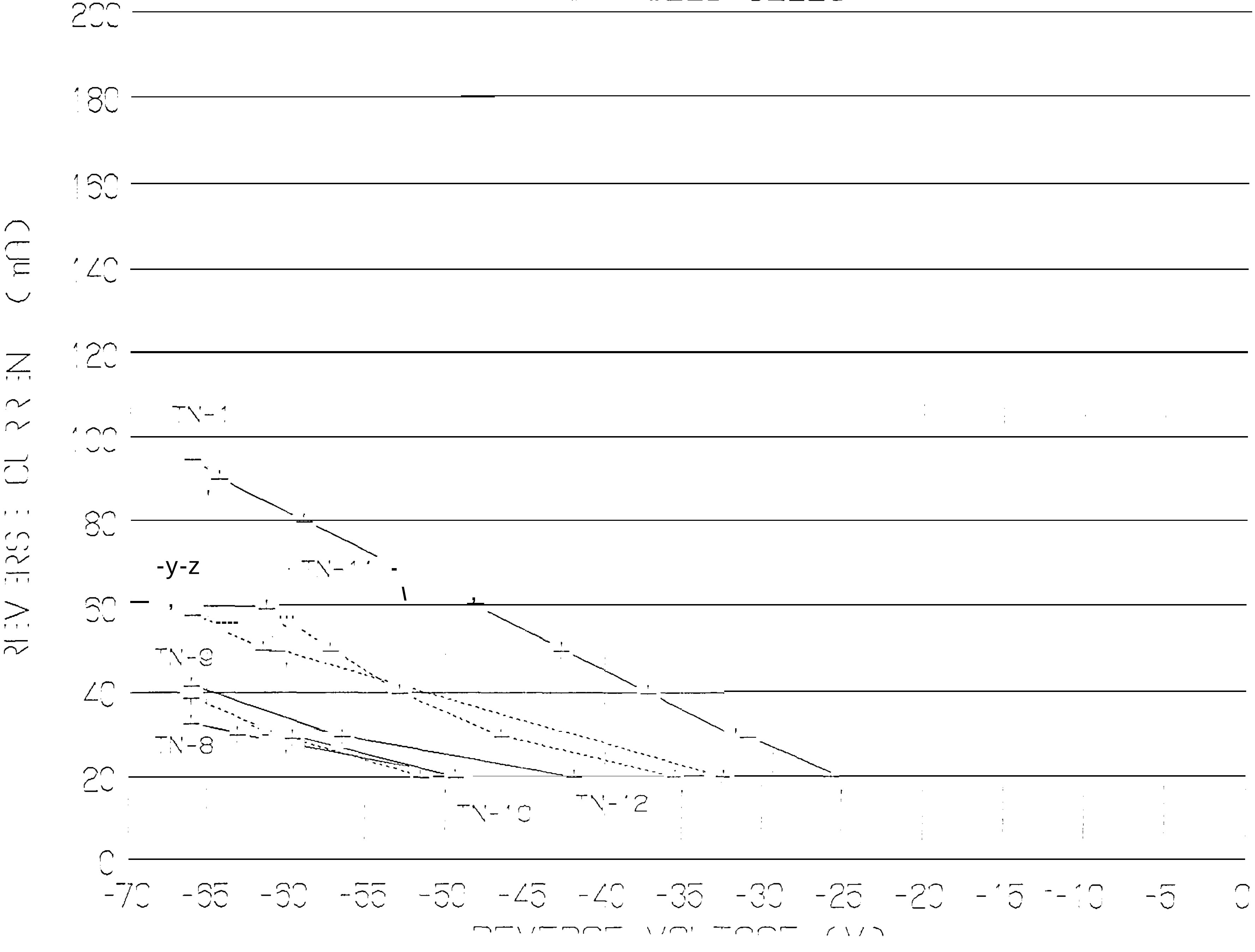


FIGURE 2-7. IR&D THIN CELLS: REVERSE BIAS TESTING
UNFAILED CELLS



# REPETITIVELY PULSED REVERSE BIAS TESTING
# TEST ARTICLES/TEST DESCRIPTION

- PURPOSE:
  - TO INVESTIGATE THE EFFECTS OF RAPID SHADOWING CYCLES ON UNDAMAGED AND FRACTURED SOLAR CELLS.

- TEST ARTICLES:
  12 PRODUCTION GRADE, THIN BORON-DIFFUSED BSF/BSR SILICON SOLAR CELLS, FABRICATED BY VENDOR A.
  CELLS BONDED individually ONTO A 6 X 6 INCH HARD ANODIZED ALUMINUM PLATE.

- TEST SEQUENCE:
  - INITIALLY PV CHARACTERISTICS AND STEADY STATE REVERSE BIAS MEASUREMENTS WERE TAKEN TO ESTABLISH EACH CELL'S PERFORMANCE AND THRESHOLD OF FAILURE DUE TO RBT.
  - CELLS WERE THEN SUBJECTED TO 525,000 RAPID REVERSE BIAS PULSES CLOSE TO BUT NOT EXCEEDING THEIR INDIVIDUAL Vbr RATING. TYPICAL PULSE **CYCLE WAS 0.25 SECONDS ON, 0.25 SECONDS OFF.** REVERSE **CHARACTERISTICS WERE MONITORED** DURING THE TEST.
  - THEREAFTER PV CHARACTERISTICS AND STEADY STATE REVERSE BIAS MEASUREMENTS WERE REPEATED.

# REPETITIVELY PULSED REVERSE BIAS TESTING. RESULTS

- ALL TWELVE CELLS SURVIVED THE PULSED REVERSE BIAS TEST.
- NINE OF THE TWELVE CELLS MONITORED DURING THE TEST RETAINED ‘ A FAIRLY CONSTANT ELECTRICAL PROFILE.
- THE RESULTS OF THE REMAINING 3 CELLS VARY QUITE SIGNIFICANTLY:
  - THE REVERSE VOLTAGE (Vr) FOR TWO OF THE CELLS INCREASED BY APPROX. 34% AT CONSTANT CURRENT.
  - THE Vr OF THE THIRD CELL DECREASED BY 25% AT NEARLY CONSTANT CURRENT. THIS DEVICE EVENTUALLY SHUNTED DURING THE STEADY STATE RBT.
- THE PV CHARACTERISTICS OF THE ELEVEN UN FAILED CELLS WERE NOT AFFECTED BY THIS TEST.

FIGURE 3-11. APSA THIN SI SOLAR CELL S/N 14
PULSED REVERSE BIAS TEST

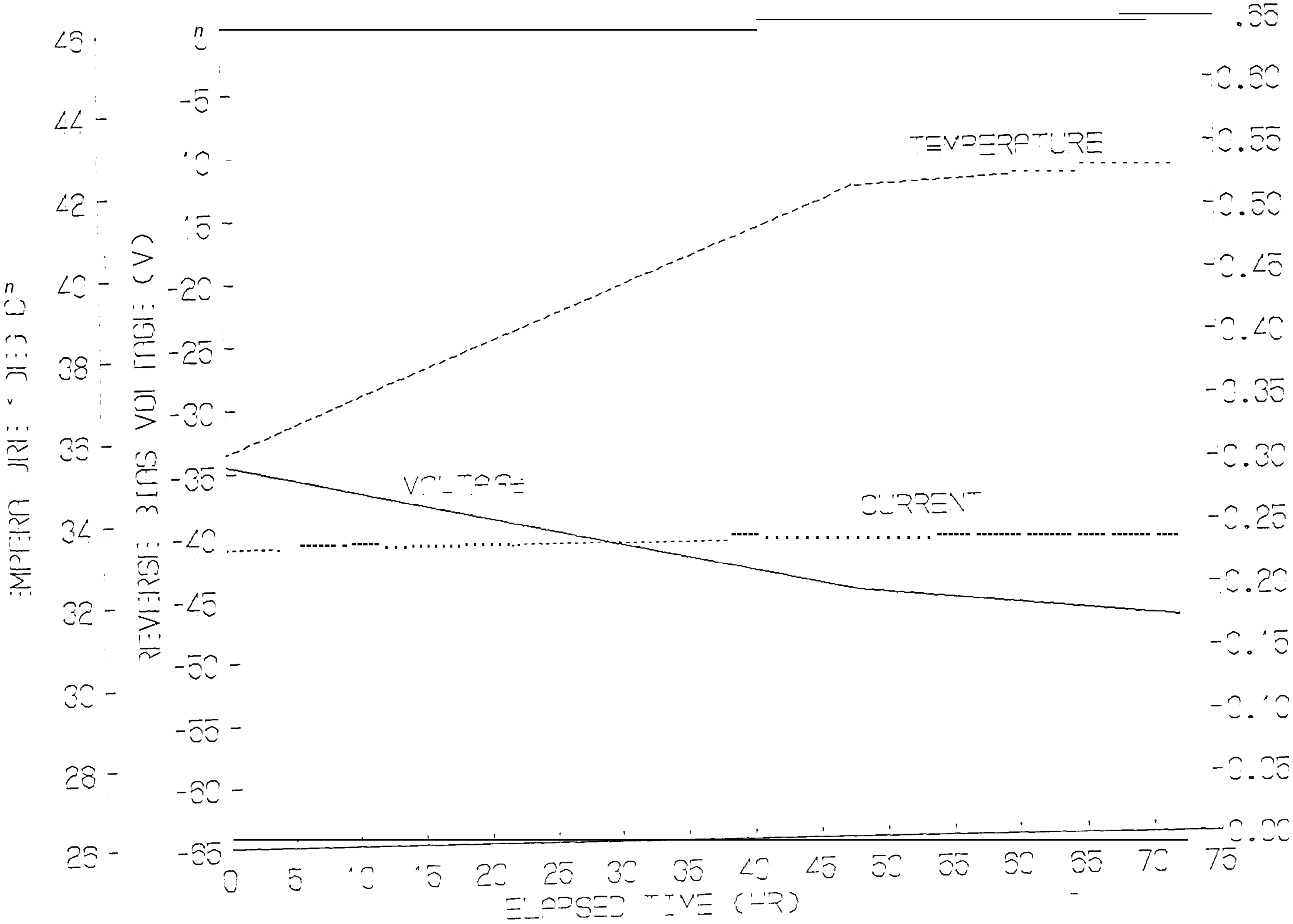


Figure 3-16. Summary of Repetitively Pulsed Reverse Bias Test Results

| Cell No. | Reverse Voltage (V) Initial | Reverse Voltage (V) Final | Reverse Current (mA) Initial | Reverse Current (mA) Final | Reverse Characteristics Change (%) Voltage | Reverse Characteristics Change (%) Current | Photovoltaic Characteristics Change (%) Voc | Photovoltaic Characteristics Change (%) Isc | Photovoltaic Characteristics Change (%) Pmp |
|---|---|---|---|---|---|---|---|---|---|
| 4 | 53.0 | 54.9 | 142.0 | 143.8 | 3.6 | 1.3 | -0.08 | 0.13 | 0.07 |
| 5 | 31.0 | 33.0 | 237.0 | 241.6 | 6.5 | 1.9 | -0.08 | 0.21 | -0.09 |
| 6 | 54.2 | 57.8 | 210.6 | 187.0 | 6.6 | -11.2 | 0.16 | 0.01 | 0.87 |
| 7 | 44.1 | 46.5 | 119.4 | 122.4 | 5.4 | 2.5 | 0.55 | -0.07 | 0.00 |
| 8 | 33.0 | 24.7 | 241.2 | 251.4 | -25.2 | 4.2 | -1.50 | -0.47 | -15.52 |
| 11 | 16.2 | 16.8 | 217.2 | 221.4 | 3.7 | 1.9 | 0.08 | -0.13 | -0.01 |
| 13 | 9.2 | 8.8 | 257.2 | 250.0 | -4.4 | -2.8 | -0.08 | 0.26 | 0.04 |
| 14 | 34.4 | 47.6 | 244.4 | 234.6 | 38.4 | -4.0 | 0.40 | 0.31 | 0.73 |
| 16 | 56.6 | 57.9 | 116.0 | 99.6 | 2.3 | -14.1 | 0.00 | 0.08 | -0.15 |
| 17 | 47.9 | 51.4 | 249.6 | 246.0 | 7.3 | -1.4 | -0.16 | 0.08 | 0.22 |
| 18 | 41.6 | 54.1 | 250.0 | 242.2 | 30.0 | -3.1 | -0.08 | 0.16 | -0.14 |
| 19 | 50.7 | 51.6 | 189.4 | 186.6 | 1.8 | -6.0 | 0.16 | 0.19 | 0.24 |

# LONG DURATION REVERSE BIAS TESTING
# TEST ARTICLES/TEST DESCRIPTION

o PURPOSE:

- TO INVESTIGATE THE EFFECTS OF EXTENDED PERIODS OF SHADOWING OR CRITICAL CELL BREAKAGE.

. TEST ARTICLES:

- 8 PRODUCTION GRADE, THIN BORON-DIFFUSED BSF/BSR SILICON CELLS FABRICATED BY VENDOR A.
  CELLS BONDED INDIVIDUALLY ONTO A 6 X 6 INCH HARD ANODIZED ALUMINUM PLATE (HEAT SINK).

• TEST SEQUENCE:

- INITIALLY PV CHARACTERISTICS AND STEADY STATE REVERSE BIAS MEASUREMENTS WERE TAKEN TO ESTABLISH EACH CELL'S PERFORMANCE AND THRESHOLD OF FAILURE DUE TO RBT.
- CELLS WERE THEN EXPOSED TO CONTINUOUS 30-DAY REVERSE BIASING CLOSE TO BUT NOT EXCEEDING THEIR INDIVIDUAL Vbr RATING. REVERSE CHARACTERISTICS WERE MONITORED DURING THE TEST.
- THEREAFTER PV CHARACTERISTICS AND STEADY STATE REVERSE BIAS MEASUREMENTS WERE REPEATED.

# LONG DURATION REVERSE BIAS TESTING RESULTS

- **ALL EIGHT CELLS SURVIVED THE** LONG DURATION **RBT EXPOSURE.**
- THEIR REVERSE CHARACTERISTICS WERE AFFECTED TO DIFFERENT DEGREES.
- IN GENERAL, THE CELLS REVERSE BIAS VOLTAGE TENDED TO INCREASE GRADUALLY IN TIME WHILE THE REVERSE CURRENT WAS **SEEN TO DECREASE SLOWLY.**
  - **ON AVERAGE,** Vr INCREASED BY **?1.2°/0,** Ir **DECREASED** BY 14.2%.
  - Vr RANGED FROM -2.3% TO 35.670, Ir DECREASED **BETWEEN -0.370.** AND -52.6% FOR **THE EIGHT CELLS.**
- **THE PV MEASUREMENTS INDICATE THAT THE** AVERAGE Isc DECREASED BY 14.3%, **WHILE** Pmax WAS **REDUCED BY** 14.8%.

FIGURE 4-4. ARSA THIN SI SOLAR CELL S/N 1
LONG-DURATION REVERSE BIAS TEST

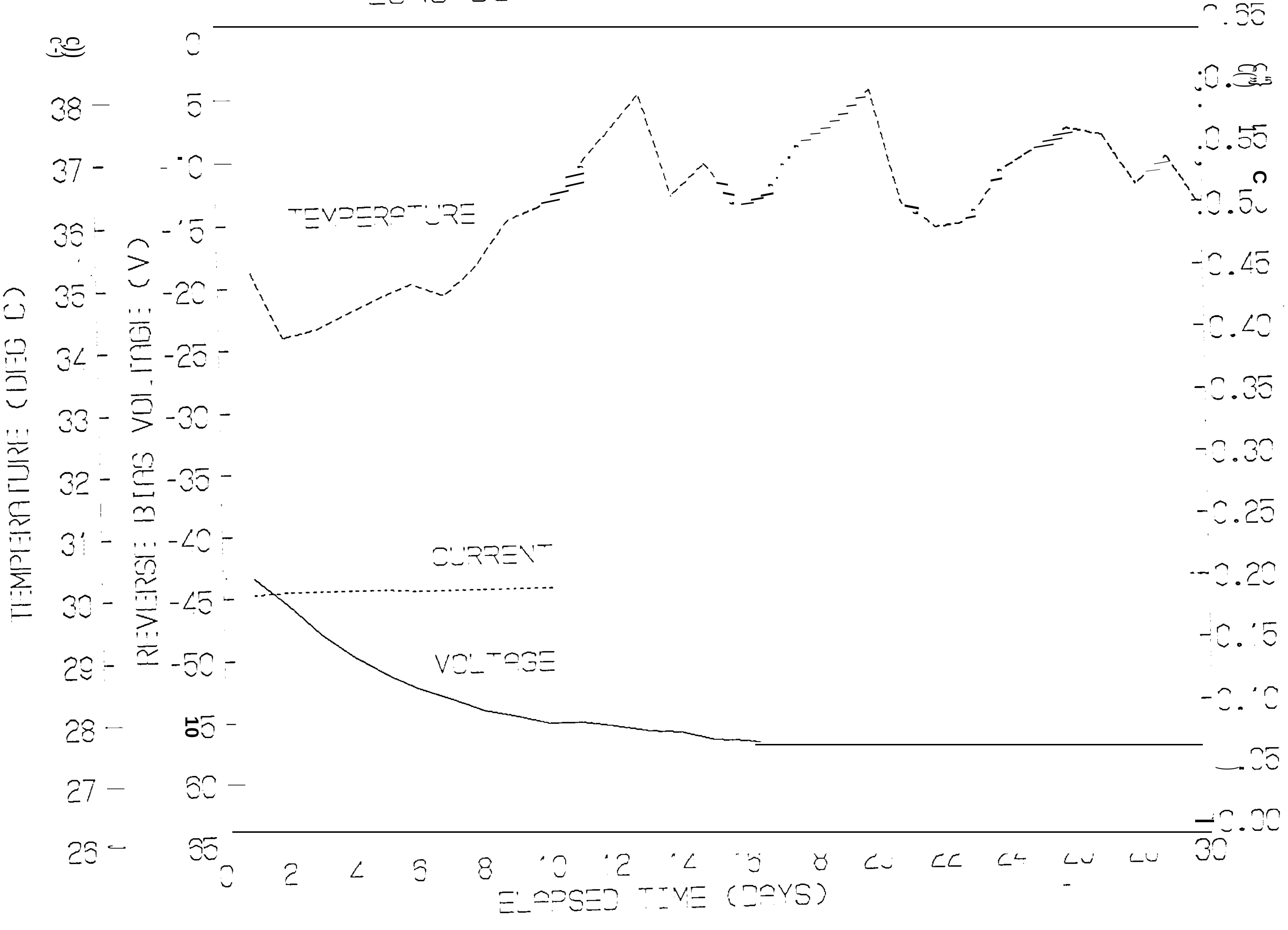


Figure 4-12. Summary of Long Duration Reverse Biasing Test Results

| Cell No. | Reverse Voltage (V) Initial | Reverse Voltage (V) Final | Reverse Current (mA) Initial | Reverse Current (mA) Final | Reverse Characteristics Change (%) Voltage | Reverse Characteristics Change (%) Current | Photovoltaic Characteristics Change (%) Voc | Photovoltaic Characteristics Change (%) Isc | Photovoltaic Characteristics Change (%) Pmp |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 43.5 | 59.0 | 202.8 | 200.4 | 35.5 | [illegible] | [illegible] | | -14.8 |
| 9 | 12.0 | 11.8 | 297.3 | 296.3 | -1.7 | -0.3 | -0.4 | -14.2 | -15.0 |
| 10 | 31.8 | 36.8 | 300.5 | 298.2 | 15.7 | -0.8 | -0.5 | -14.2 | -14.5 |
| 12 | 52.7 | 60.7 | 201.0 | 162.4 | 15.2 | -19.2 | -0.6 | -14.0 | -14.5 |
| 15 | 8.8 | 8.6 | 303.1 | 299.8 | -2.3 | -1.1 | -0.5 | -14.8 | -15.3 |
| 20 | 54.3 | 60.6 | 196.3 | 154.8 | 11.6 | -21.1 | -0.8 | -14.4 | -15.0 |
| 21 | 55.9 | 60.7 | 173.8 | 82.4 | 8.6 | -52.6 | -0.7 | -14.4 | -14.8 |
| 22 | 56.8 | 60.7 | 194.7 | 161.0 | 6.9 | -17.3 | -0.4 | -14.2 | -14.5 |

# TEMPERATURE EFFECTS ON CELL REVERSE PROPERTIES
# TEST ARTICLES/TEST DESCRIPTION

- **PURPOSE:**
  - **TO DETERMINE THE CELLS'S REVERSE BIAS THRESHOLD AS A FUNCTION OF TEMPERATURE.**

. TEST ARTICLES:
  - 32 PRODUCTION GRADE, BORON-DIFFUSED BSF/BSF THIN SILICON CELLS FABRICATED BY VENDOR A.
    **DEVICES WERE BONDED** ONTO 5.6" X 7.7' **HARD ANODIZED** ALUMINUM PLATES (HEAT SINK), 8 CELLS PER PLATE.
  - TEST ARTICLES WERE INSTALLED INTO VACUUM CHAMBER **(70** TORR).

- TEST SEQUENCE:
  - INITIALLY PV CHARACTERISTICS AND STEADY **STATE RBT WERE TAKEN** AT **28 C TO ESTABLISH EACH CELL'S BASELINE RESPONSE AND THE TRESHOLD OF FAILURE DUE TO RBT.**
  - DURING RBT THE CELLS WERE STRESSED AT INCREASINGLY HIGHER VOLTAGES AND CURRENTS.
  - THEREAFTER, THE PV AND RBT MEASUREMENTS WERE REPEATED SEQUENTIALLY AT 75 C, 125 C, -75 C, AND -150 C.

# TEMPERATURE EFFECTS ON CELL REVERSE PROPERTIES
## RESULTS

- THE CELLS' Vr INCREASED WITH INCREASING ENVIRONMENTAL TEMPERATURES AND CORRESPONDINGLY DECREASED WITH DECREASING TEMPERATURES.

- CELL FAILURES OCCURED ONLY DURING TESTING AT ELEVATED TEMPER ATURES. THE FOLLOWING CELL FAILURES WERE RECORDED DURING RBT:

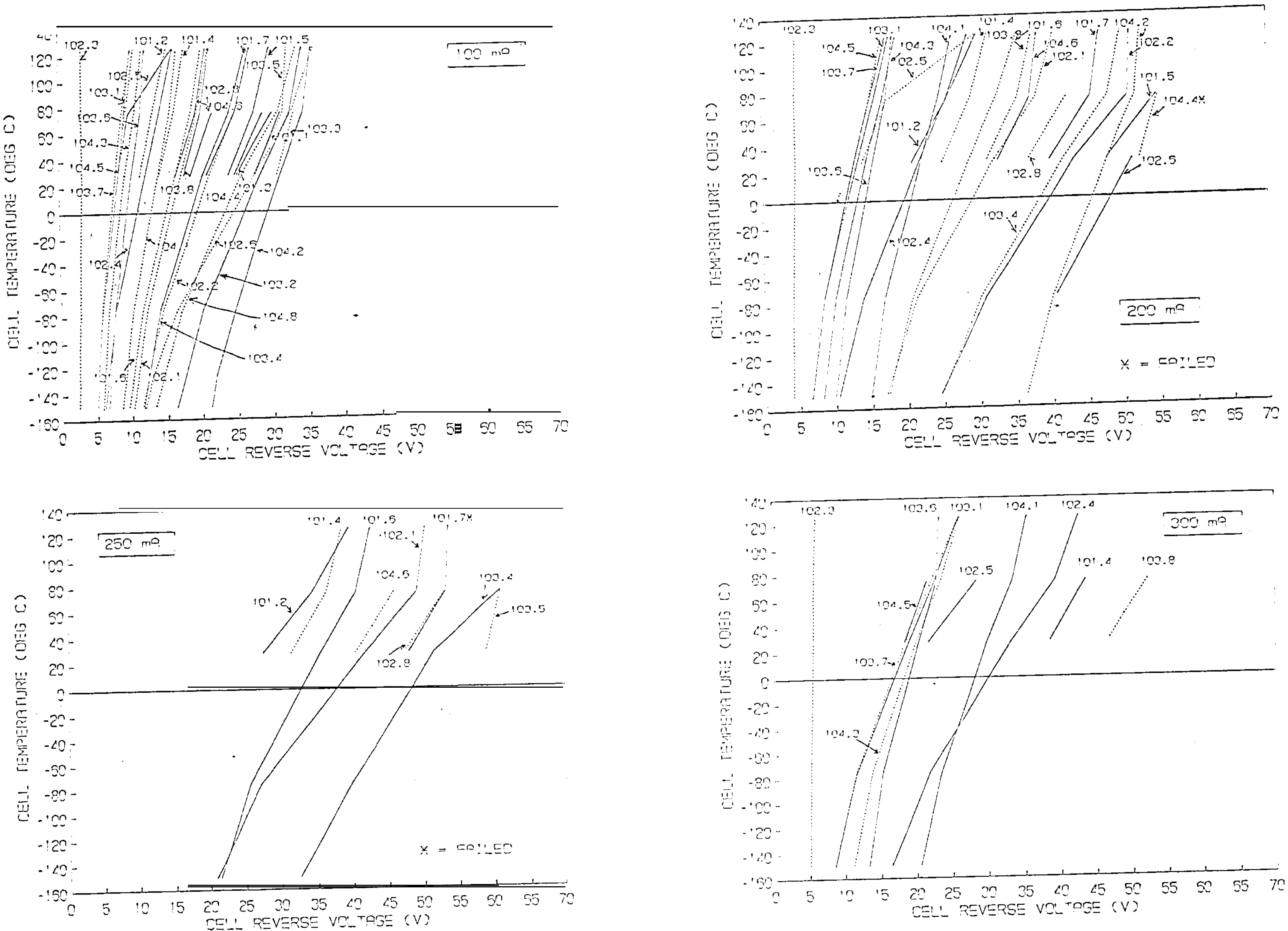
| TEMPERATURE ( C) | NUMBER OF FAILURES SHORTED | SHUNTED |
|---|---|---|
| -150 | o | 0 |
| - 7 5 | o | 0 |
| 28 | 0 | 2 |
| 75 | 3 | 1 |
| 125 | 1 | 7 |

- PV CHARACTERISTICS OF THE 17 UNDAMAGED CELLS REMAINED UNAFFECTED.

- Pmax OF THE 10 SHUNTED CELLS DECREASED BY AN AVERAGE OF 60.6%; THE Voc OF **THE SHORTED DEVICES DROPPED BY 68%.**

Figure 5-2

# TEMPERATURE EFFECTS ON APSA SOLAR CELL REVERSE BIAS CHARACTERISTICS



# EFFECTS OF CHARGED PARTICLE IRRADIATION TEST ARTICLES/TEST DESCRIPTION

- PURPOSE:
  - TO INVESTIGATE THE EFFECTS OF ELECTRON AND PROTON IRRADIATION (APSA MISSION ENVIRONMENT) ON CELL PV AND REVERSE BIAS CHARACTERISTICS.

- TEST ARTICLES:
  - 10 PRODUCTION GRADE, UNGLASSED BORON-DIFFUSED BSF/BSR THIN SILICON CELLS FABRICATED BY VENDOR A.

- TEST DESCRIPTION:

  INITIALLY PV CHARACTERISTICS AND STEADY STATE RBT WERE TAKEN AT 28 C TO ESTABLISH EACH CELL'S ELECTRICAL CHARACTERISTICS.

  CHARGED PARTICLE IRRADIATION:

  * 5 CELLS IRRADIATED WITH 1 MeV ELECTRONS TO 1E15 E/CM$^2$
  * 5 CELLS IRRADIATED WITH 6 MeV PROTONS TO 1E11 P/CM$^2$

  THEREAFTER PV CHARACTERISTICS AND STEADY STATE RBT WERE REPEATED.

# EFFECTS OF CHARGED PARTICLE IRRADIATION RESULTS

- ALL CELLS SURVIVED THIS TEST PHASE; ONE CELL FAILED DUE TO UNINTENTIONAL OVERSTRESS.
- THE REVERSE CHARACTERISTICS OF THE CELLS WERE NOT GREATLY AFFECTED BY EXPOSURE TO THE CHARGED PARTICLE ENVIRONMENT.
  - Vr AT **CONSTANT CURRENT INCREASED BY** AN AVERAGE OF
    - 6.7% FOR PROTON IRRADIATED CELLS,
    - 5.3% FOR ELECTRON IRRADIATED CELLS.
- CHARGED PARTICLE IRRADIATION SEVERELY AFFECTED CELL OUTPUT:
  - Pmax DEGRADED BY
    - 37% FOR CELLS IRRADIATED WITH PROTONS
    - 32% FOR CELLS IRRADIATED WITH ELECTRONS.

# Figure 6-3. Radiation Effects on APSA Solar Cell Characteristics
## Summary of Proton Irradiation Data (4 Cells**)

| Radiation Effects on PV Characteristics | | | |
|---|---|---|---|
| Parameter | Pre-Irradiation | Post-Irradiation | % Net |
| Avg. Voc (V) | 0.s1194 | 0.53711 | 87.77% |
| Avg. Isc (A) | 0.52953 | 0.41739 | 78.82% |
| Avg. Vmp (V) | 0.50940 | 0.44225 | 86.82% |
| Avg. Imp (A) | 0.49922 | 0.39196 | 78.51% |
| Avg. Pmax (W) | 0.25424 | 0.17327 | 68.15% |
| Avg. Fill Factor | 0.78459 | 0.77290 | 98.51% |

| Rad. and Rev. Biasing Effects on PV Characteristics | | | |
|---|---|---|---|
| Parameter | Pre-Irradiation | Post-irradiation | % Net |
| Avg. Voc (V) | 0.58584 | 0.53760 | 91.77% |
| Avg. Isc (A) | 0.52786 | 0.41764 | 79.12% |
| Avg. Vmp (V) | 0.50903 | 0.44165 | 86.76% |
| Avg. Imp (A) | 0.49620 | 0.39269 | 79.14% |
| Avg. Pmax (W) | 0.25240 | 0.17336 | 68.68% |
| Avg. Fill Factor | 0.78278 | 0.77215 | 98.64% |

| pre-/Post-Irradiation Reverse Bias Characteristics | | | | |
|---|---|---|---|---|
| Cell ID No. | Ir (mA) | Vr (V) | | % Net |
| | | Pre-Irrad. | Post-Irrad. | |
| 255 | 175 | 35.6 | 39.8 | 108.74% |
| 307 | 100 | 57.9 | 55.3 | 95.51% |
| 315 | 225 | 35.6 | 36.2 | 101.69% |
| 318** | 150 | 51.3 | 57 | 111.11% |
| 324 | 200 | 45.2 | 53.9 | 1?5.57% |

** Cell ID No. 318 failed.

## Figure 6-2. Radiation Effects on APSA Solar Cell Characteristics Summary of Electron irradiation Data (5 Cells)

| Radiation Effects on PV Characteristics | | | |
|---|---|---|---|
| Parameter | Pre-Irradiation | Pos:-Irradiation | % Net |
| **Avg.** Voc **(V)** | 0.s?28$? | 0.50928 | 83.09% |
| **Avg.** Isc (A) | 0.52993 | 0.40283 | 76.02% |
| **Avg.** Vmp **(V)** | 0.51045 | 0.42344 | 82.95% |
| Avg. Imp **(A)** | 0.49588 | 0.37746 | 76.12% |
| **Avg.** Pmax **(W)** | 0.25323 | 0.15975 | 63.08% |
| Avg. Fill Factor | 0.77970 | 0.77788 | 99.77% |

| Rad. and *Rev. Biasing Effects* on **PV Characteristics** | | | |
|---|---|---|---|
| **Parameter** | Pre-**Irradiation** | Post-Irradiation | % **Net** |
| **Avg.** Voc (V) | 0.61143 | **0.50957** | **83.35%** |
| **Avg.** Isc **(A)** | 0.52799 | 0.40297 | 76.32% |
| Avg. Vmp (V) | 0.51074 | 0.42441 | 83.10% |
| Avg. Imp (A) | 0.49135 | 0.37639 | 76.60% |
| Avg. Pmax (W) | 0.25069 | 0.15976 | 63.73% |
| Avg. Fill Factor | 0.77859 | 0.77787 | 99.91% |

| Pre-/Post-Irradiation Reverse Bias Characteristics | | | | |
|---|---|---|---|---|
| Cell ID No. | Ir (mA) | Vr (v) | | % Net |
| | | Pre-Irrad. | Post-Irrad. | |
| **270** | **225** | 8.1 | **8.2** | 101.23% |
| **277** | **75** | **55.1** | **52.8** | 96.47% |
| **285** | **300** | 36.8 | **39.1** | 106.25% |
| 291 | 1 **54/175** | 56.1 | 66 | 117.65% |
| **302** | '200 | 31.2 | **32.8** | 105.13% |

# APSA CELL FAILURE MODES ANALYSIS

- CELL FAILURES ARE THE RESULT OF STRESSES INDUCED DURING REVERSE BIASING SUCH THAT CATASTROPHIC JUNCTION BREAKDOWN RESULTS.

- A VARIETY OF DEFECTS ARE CREATED IN THE CELL STRUCTURE AS A CONSEQUENCE OF FAILURE:
  - THERMALLY INDUCED DECOMPOSITION OF MATERIALS.
  - EVAPORATION OF MATERIALS.
  - ABSORPTION OF METALS INTO THE SILICON CRYSTAL LATTICE.
  - SOLDER REFLOW.
  - STRIATIONS EMANATING FROM THE BREAKDOWN SITE ON CELL BACK SIDE.

- PHYSICAL DAMAGE AND PROCESSES **WERE OBSERVED/ANALYZED WITH:**
  THERMOGRAPHY TO OBSERVE THE FORMATION OF HOT SPOTS.
  [R CAMERA WHICH ALLOWS IDENTIFICATION OF DEFECT SITES.
  SCANNING ELECTRON MICROSCOPE (SEM).
  ENERGY DISPERSIVE X-RAYS (EDX) USED TO IDENTIFY LAYERING SYSTEM.
  ELECTRON BEAM INDUCED CURRENTS (EBIC) TO LOCATE DAMAGE SITE WITHIN THE DEVICE STRUCTURE.

# APSA CELL FAILURE MODES ANALYSIS CONCLUSIONS

- REVERSE BIAS FAILURES OF CELLS ARE INSTANTANEOUS AND CATASTROPHIC.
- CELL FAILURES ARE DUE TO JUNCTION SHORTING OR SHUNTING.
- OPEN CIRCUIT FAILURES 'HAVE NOT BEEN OBSERVED.
- **AT FAILURE THE CELL TEMPERATURE IN THE 'BREAKDOWN REGION EXCEEDS 1400 C. MELTING AND POSSIBLY EVAPORATION OF CELL MATERIALS ARE THE CONSEQUENCE.**
- **SOLDER SCAVENGING OF THE CONTACT ME TALL IZATION,** AND POSSIBLE **DECOMPOSITION OF MATERIALS WITH SUBSEQUENT CELL SHUNTING WAS NOT OBSERVED.**
- **LOCAL SOLDER REFLOW WAS OBSERVED BUT AFFECTED AREA** WAS **TOO SMALL TO IMPACT THE INTERCONNECTOR SYSTEM.**
- **CELL STRESS FRACTURES COULD NOT BE ASSOCIATED WITH REVERSE BIASING. THEY ARE DIFFICULT TO DETECT AND MOST LIKELY THE RESULT OF MECHANICAL STRESSES INDUCED BY HANDLING.**

SEM/EDX Image of APSA Cell Damage Sites Induced during Reverse Biasing

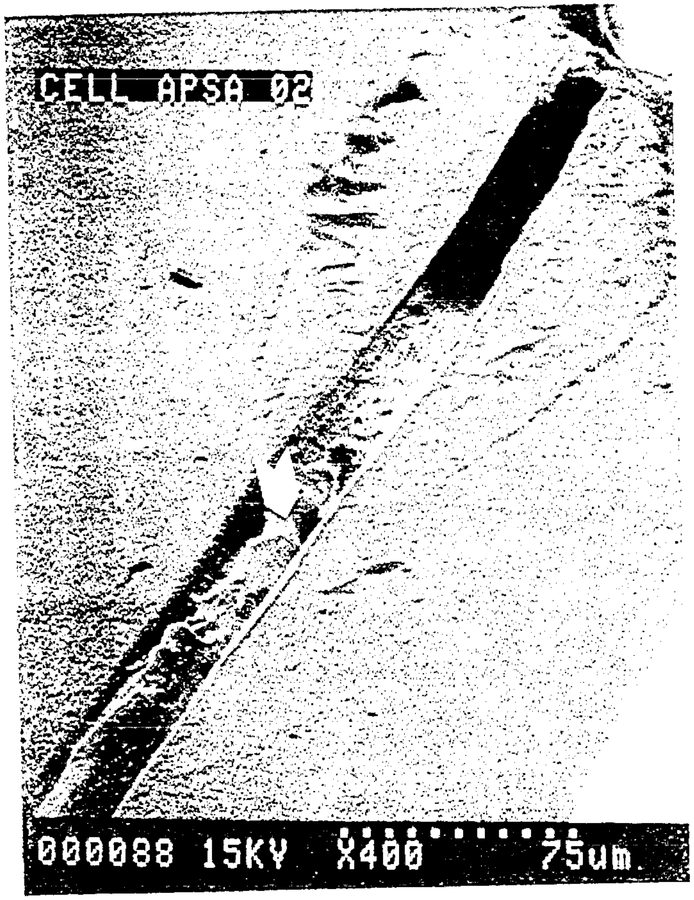



Figure 6A. 400 x Magnification


Figure 6B. 1700 x Magnification

Cell No. APSA 02 Area 1

SEM/EDX Image of APSA Cell Damage Sites Induced during Reverse Biasing


Figure 12A. 300 ×

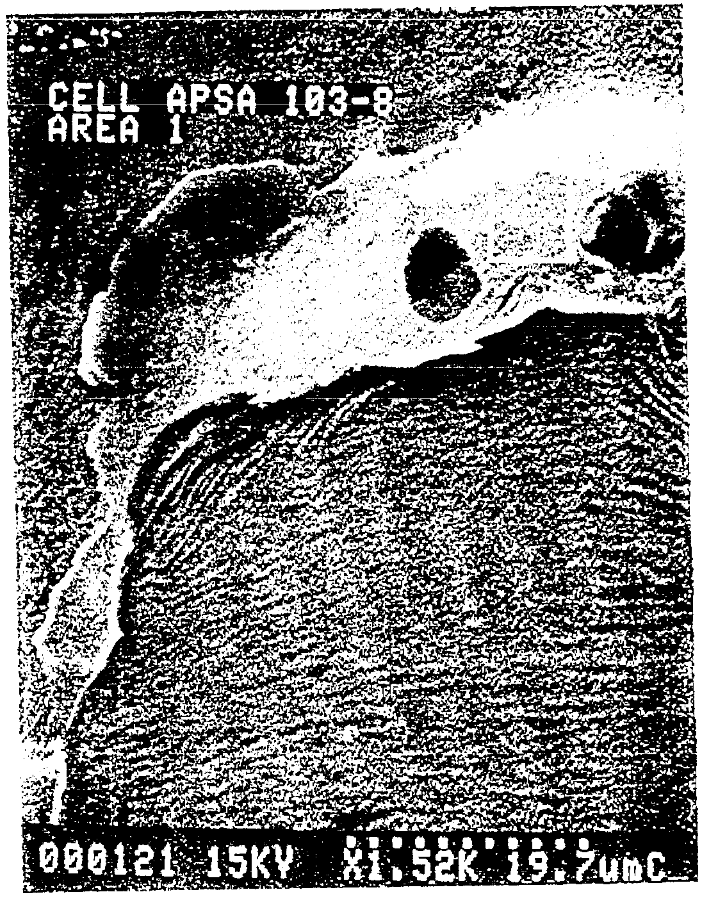



Figure 12B. 520 × Magnification

Cell APSA 103-8

SEM Image of APSA Cell Damage Sites Induced during Reverse Biasing

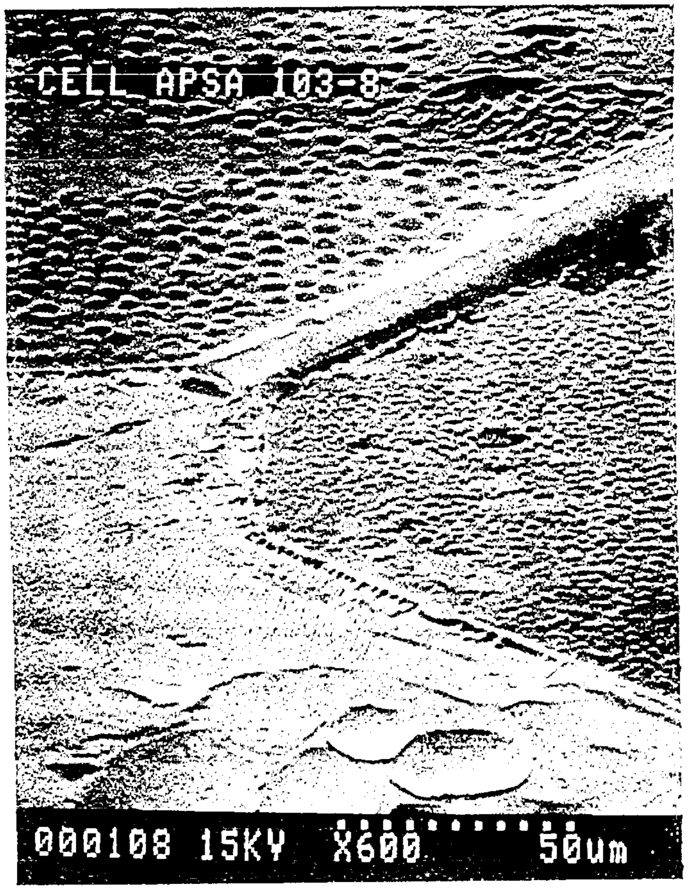
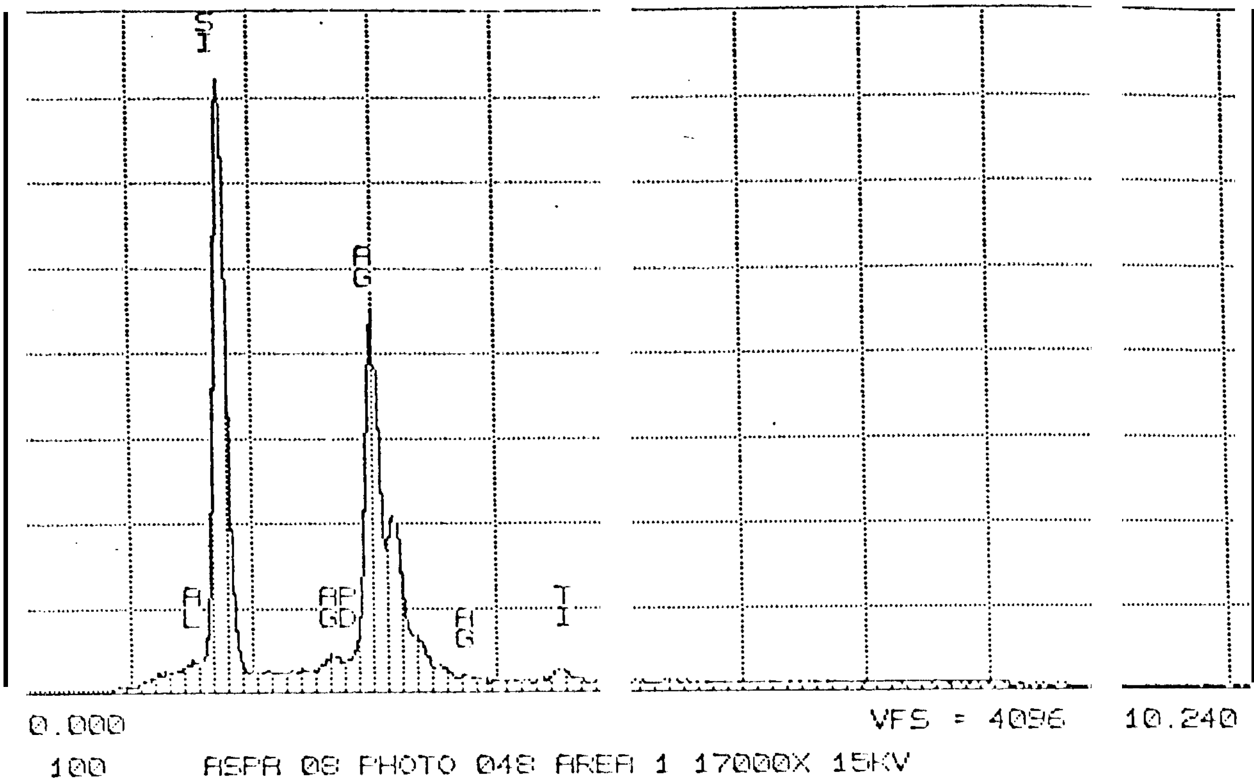



Figure 12C. 600 x Magnification


Figure 12D. 170 x Magnification

Cell 103-8

MATERIALS AND PROCESSES DEPARTMENT WED 27-JAN-93 09:03
Cursor: 0.000KeV = 0




SQ: QUANTIFY

ASPA 08 PHOTO 048 AREA 1 17000X 15KV
Standardless Analysis
15.0 kV 35.0 Degrees

Chi-sqd = 1.62

| Element | Rel. K-ratio | Net Counts |
|---|---|---|
| Al-K | 0.00213 +/- 0.00164 | 313 +/- 241 |
| Si-K | 0.26995 +/- 0.00238 | 45229 +/- 398 |
| Pd-L | 0.01181 +/- 0.01056 | 987 +/- 883 |
| Ag-L | 0.67870 +/- 0.01487 | 48026 +/- 1052 |
| Sn-L | 0.01985 +/- 0.00793 | 1350 +/- 539 |
| Ti-K | 0.01756 +/- 0.00192 | 1343 +/- 147 |

ZAF Correction 15.00 kV 35.00 deg
No.of Iterations = 1

| Element | K-ratio | Z | A | F | ZAF | Atom% | Wt% |
|---|---|---|---|---|---|---|---|
| Al-K | 0.002 | 0.900 | 1.596 | 0.990 | 1.422 | 0.57 | 0.26 |
| Si-K | 0.234 | 0.874 | 1.384 | 0.993 | 1.2(2)1 | 59.02 | 28.04 |
| Pd-L | 0.010 | 1.088 | 1.067 | 0.999 | 1.160 | 0.66 | 1.18 |
| Ag-L | 0.587 | 1.082 | 1.046 | 0.999 | 1.131 | 36.40 | 66.43 |
| Sn-L | 0.017 | 1.129 | 1.190 | 1.000 | 1.343 | 1.15 | 2.31 |
| Ti-K | 0.015 | 0.969 | 1.207 | 1.000 | 1.169 | 2.19 | 1.78 |
| | | | | | | Total= | 100.00% |

Figure 11. Cell No. APSA 08 EDX Chart, Area 1

SEM/EDX Image of APSA Cell Damage Sites Induced during Reverse Biasing

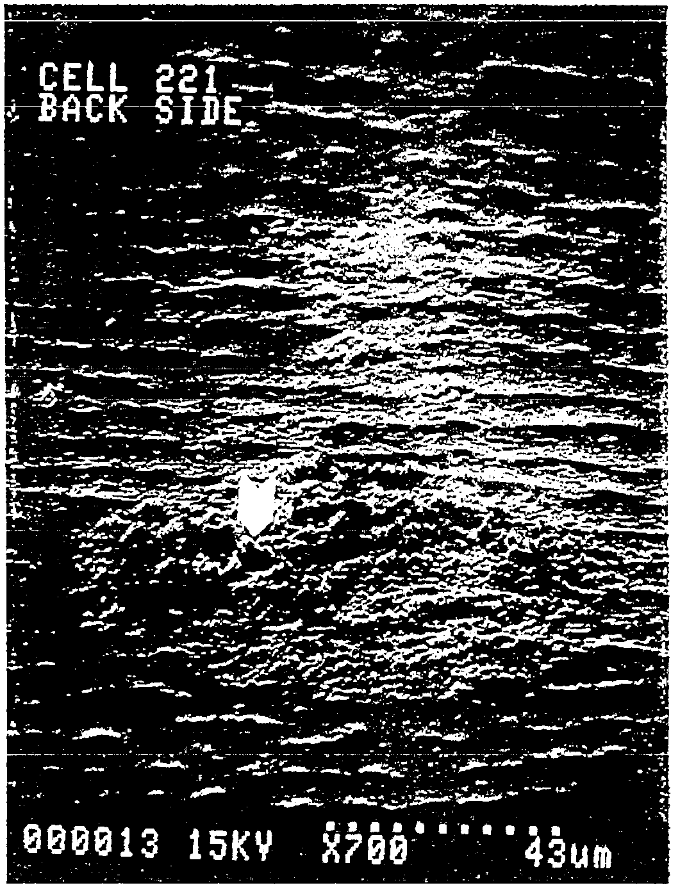
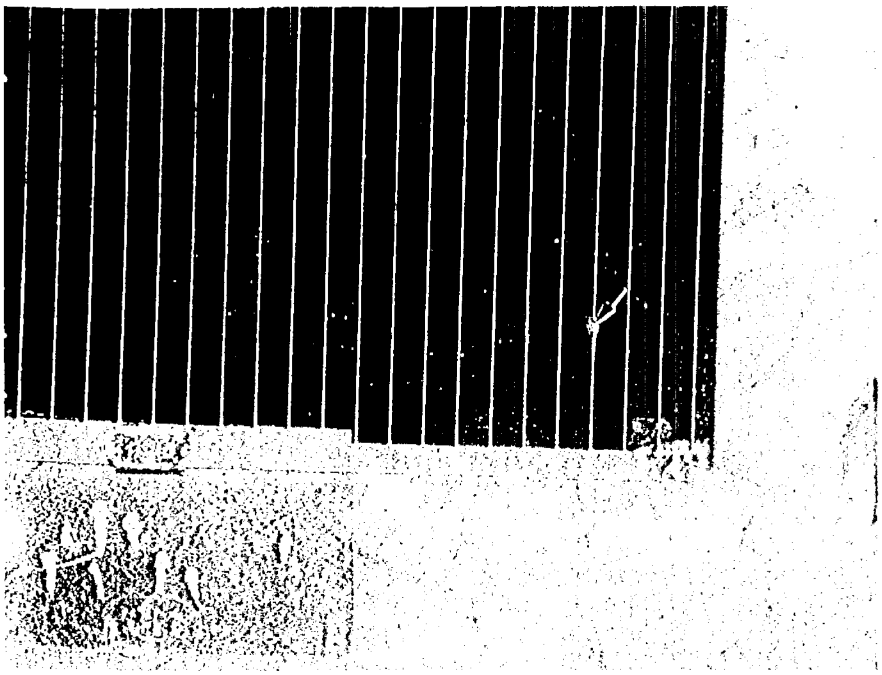


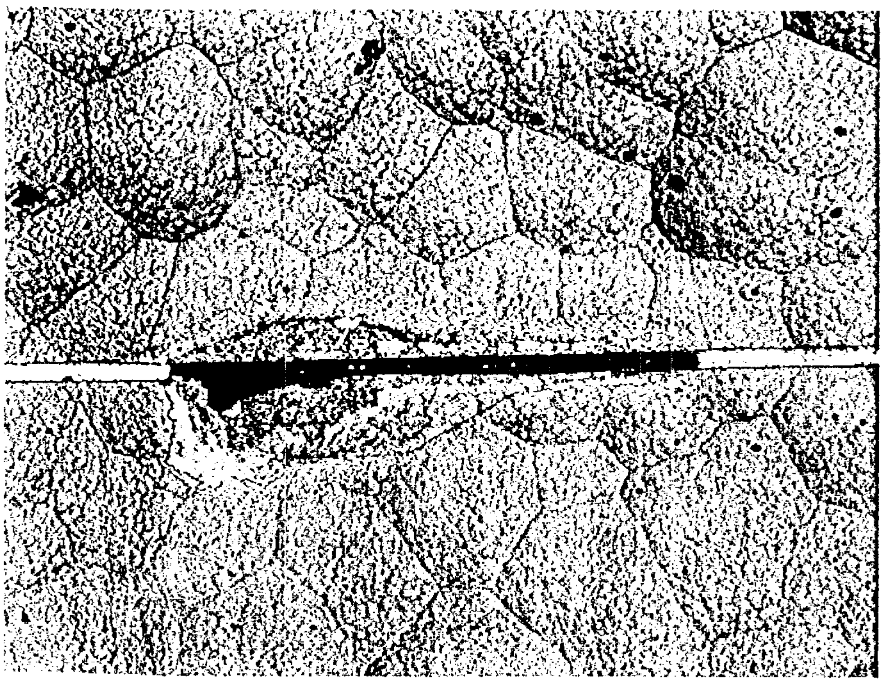

Figure 16A. 700 x Magnification


Figure 16B. 3000 x

Cell No. 221



M =5.8X
S/N 2
Overall view showing the failure site (arrow).

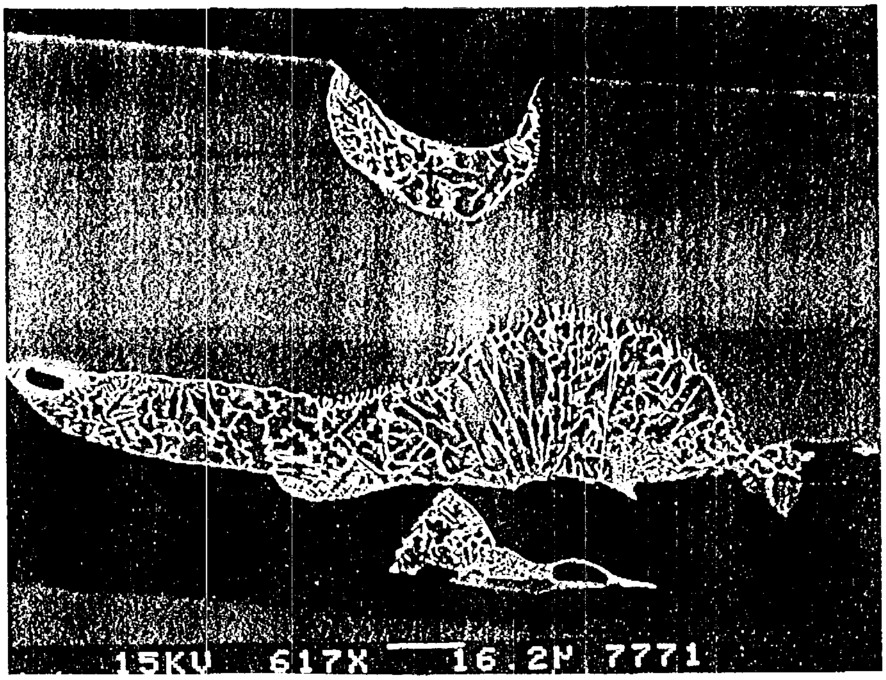


M =50X
S/N 2
Detailed view showing the failure site which appears to be associated with electrical overstress damage (fusing of the Ag into the substrate).

T= 0°

SIN 2

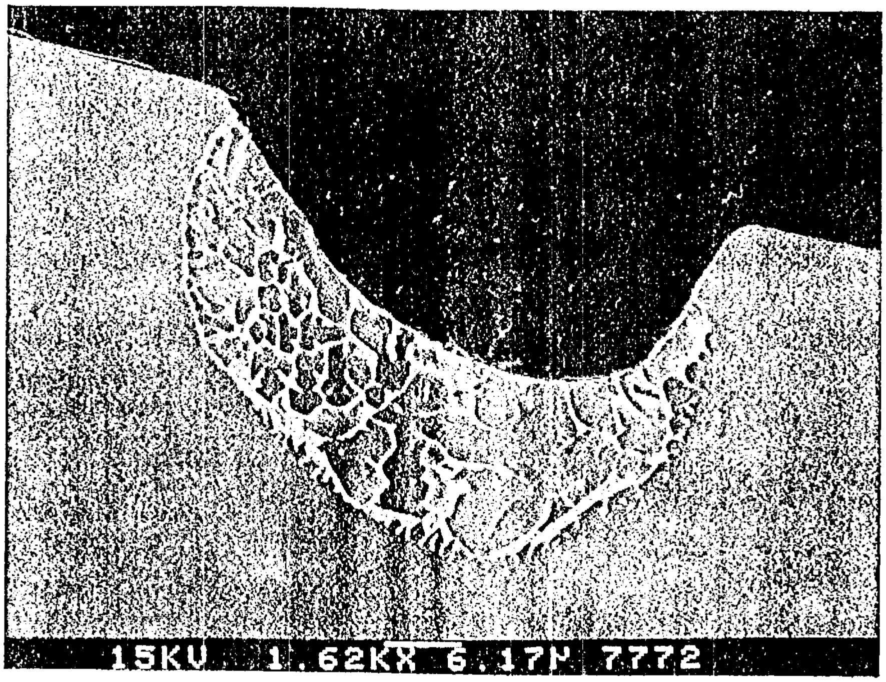
Overall precision cross-sectional view showing the overstress damage site.

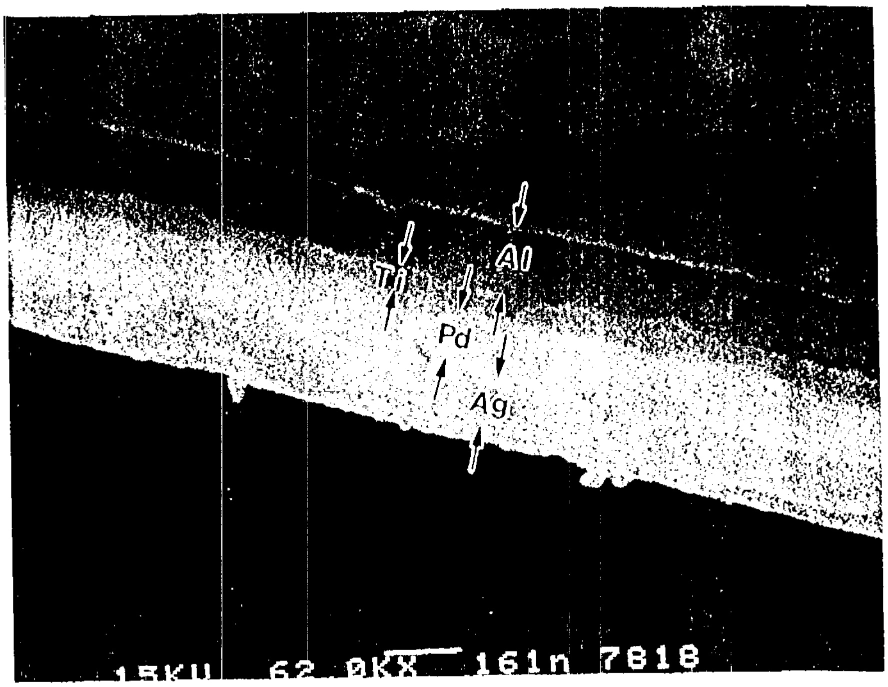



T= 0°

S/N 2

Detailed cross-sectional view showing microalloying of the top Iuetalli7.alien into the silicon substrate,






T= 0°
S/N 111
Close-up view showing the backside metallization layers.